effort spent: like getting gold from sea water, there is plenty there but it costs more in cash to get it than the value of the return. Jackson (1954) calculated the cost of various methods and returns and concluded that plankton would cost about twenty times the figure charged for the highest priced fish. This might be worth it for some special compound of great pharmacological value, but not for animal feeding.

No, with engineering difficulties and costs as they stand now—and this does not necessarily also mean in the future—it is far better to let the various marine organisms work for us, free of charge, 24 h a day, no overheads and no strikes, and then catch the resulting fish rationally even if they do represent only a fraction of the actual production of the sea.

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The conservation of fish stocks

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Covering as they do seven-tenths of the earth's surface, the seas and oceans of the world have been, and seem likely always to be, an important source of supply of man's food. Though now, and for the foreseeable future, fishing may be likened to hunting, rather than to agriculture and, at least in the open sea, nothing can be done directly to improve the stock of fish, the future of a fishery can be greatly affected by the quantity and quality of the catch removed from the stock. Conservation of fish stocks is therefore concerned with suitable regulation of fishing (how much and what sort of fish to catch), and the main problems are firstly establishing the facts as to how fishing controls the level of the stocks and hence future catches, and secondly deciding in the light of these facts how the fishery should be regulated to the best interests of all concerned in it, producer and consumer, present and future.

The influence that intensive fishing could have on fish stocks first became apparent at the end of last century when the rapid expansion of steam trawling in the North Sea was followed by an almost equally rapid decline in the abundance of the most valuable species, particularly plaice. Confirmation of the connexion between fishing and stock was given when the reduction of fishing in the 1914–18 war resulted in a great increase in stock, followed by a corresponding decrease after 1919. The same sequence of events occurred in 1939–45, the plaice in 1945 being about ten times as abundant as in 1938. During the interwar period the general understanding and theory of the overfishing problem was slowly developed, and since the war a satisfactory quantitative theory of fish populations has been produced (see Beverton & Holt, 1957). Essentially the theory depends on following a brood of fishes from the time the fish become vulnerable to fishing, until they are all dead. Their numbers at any time will depend on the initial numbers—the recruits—and the mortality rate since. The latter is conveniently split between that due to fishing, and that due to other or 'natural' causes. The number caught in any short time interval will be proportional to the product of the number alive during that time and the fishing rate. The total number caught can then be obtained as the integral over the life span of the fish. The catch in weight is obtained similarly, by introducing a suitable mathematical expression for the growth of the fish, giving its weight at any time, so that the weight caught is the integral over the life span of the number caught in each interval of time multiplied by the average weight of the individual fish at that time. Fortunately there is a growth equation, that of von Bertalanffy (1938) which both fits the observed weight at age of most fish and gives an expression that can be integrated quite easily. Other important characteristics of the stock, e.g. its abundance in numbers or weight, the average size of fish in the catch, may be calculated fairly readily.

Of the factors which influence the yield two are directly under human control: the fishing mortality, which is directly proportional to the fishing effort—the amount of fishing carried out—and the age or size at which the fish are first liable to capture. The latter, though not completely controllable may be varied over quite wide limits, e.g. by the use of large-meshed nets which allow the small fish to pass through. The other important factors such as recruitment and growth cannot be affected directly, unless we look forward to the distant future of extensive fish rearing or fertilization of the sea. There are indirect effects, in that it would be expected that an increased stock (due to successful regulation) would give a greater number of young fish, but the greater crowding would slow down the growth and increase the mortality due to disease and parasites. In fact there are few, if any, well-established instances of the size of the spawning stock of marine fish influencing the resultant number of young fish—which is perhaps not surprising if we remember the vast number of eggs, running sometimes into millions, which a single female fish can produce. Again, influence of stock size on growth has rarely been strongly marked, even for some of the North Sea stocks which increased by a factor of about ten between 1938 and 1945.

As, therefore, the effects of density-dependent recruitment, growth and mortality are ill-defined, and the first acts in opposite manner to the other two, they have often, quite reasonably in the lack of better data, been assumed to be negligible and the recruitment, growth and natural mortality assumed to be constant. If this assumption is made then the effect of changes in the amount of fishing, or in the age at first capture, can be readily evaluated, given the necessary data on the present values of the relevant factors.

Without going through the mathematics, we may now examine these effects, as calculated by the relevant equations, considering first changes in the amount of fishing. As fishing is increased the number of fish caught will also increase, and will continue to increase with increased amount of fishing, but tending to an asymptotic level, at which all the fish are caught as soon as they become vulnerable to the fishing gear used. However, as the amount of fishing increases, the increased mortality will decrease the average expectation of life of each fish and hence the average age and size of fish in the catch. The total weight of the catch will at first increase with increasing fishing almost as fast as the numbers in the catch, but more slowly as the size of the individual fish falls off; not infrequently the weight caught reaches a maximum at a certain level of fishing and thereafter decreases. A hypothetical example (differing not too much from that of the North Sea plaice) of how this may come about is of a fish which becomes vulnerable to fishing at a weight of $\frac{1}{4}$ lb., but could grow up to 15–20 lb.; with no fishing the average weight of a fish is 2–3 lb. At a low level of fishing, out of every hundred fish reaching a catchable size ten are caught at an average of 2 lb., 20 lb. in all; at an intermediate level fifty fish (average 1 lb., total 50 lb.), whereas at a very high amount of fishing ninety fish are caught, but each weighs on the average $\frac{1}{3}$ lb. and the weight caught is only 30 lb. It may be seen that the conditions for the existence of such a maximum in the 'yield curve' (the plot of weight caught against amount of fishing) are in general terms a growth pattern such that a fish can reach several times the weight at which it is first vulnerable to the fishery, and a low rate of natural mortality so that, with little fishing, it has a good chance of reaching a large size. These conditions are in fact fulfilled by many of the important fish stocks, e.g. cod, plaice and haddock. The presence of a maximum in the yield curve has been known for a long time for several stocks, and it has often been considered that the objective of conservation measures should be to hold the fishing effort at the level giving this maximum catch.

Besides alterations in the total amount of fishing, the effect of the fishing on the stock, and hence the catch, can also be altered by changes in the size at which fish are first liable to be caught, e.g. a change in the size of the meshes in the net. As it is increased the average size of the fish in the catch increases, but the number caught decreases, as more and more fish die before reaching the catchable size. Taken together the two effects give a maximum catch at some intermediate size. This size will be determined by the chances of catching the fish, given by the relative magnitudes of the death rate due to fishing alone and to all causes, and by the amount the fish is likely to grow. The optimum size of first capture is therefore determined *inter alia* by the amount of fishing; with heavy fishing it pays to wait and let the fish grow. More interesting, and in contrast to the earlier result, the catch obtained by using the best size of first capture for a given amount of fishing increases continuously with the amount of fishing, never reaching a maximum.

In theory then, allowing variation in both amount of fishing and size of first capture, the greatest catch would be obtained with a relatively large size at first capture and a virtually infinite amount of fishing, i.e. by waiting till the fish reach the best size and then catching them all at once—which is indeed effectively a technique often used in the limited areas of fish ponds, but impractically costly in the open sea.

These results, giving the catch in weight, for a single species, may quite easily be extended in several ways. For instance, the size composition of the fish in the catch is calculable and, given the present relation between the size of fish and value, there is no difficulty in handling the biological data necessary to predict the value of the catch at any future level of fishing, though economic effects might alter the picture. Because conservation measures usually increase the average size of fish in the catch, and pound for pound large and medium-sized fish fetch better prices than small fish—in part because they have a slightly higher proportion of edible flesh—gains due to conservation measures calculated, as they usually are, in terms of weight will underestimate the gain in value.

Though sometimes fishing in a region may be effectively confined to one species, in temperate waters there may be half a dozen or more commercially important species, and perhaps a hundred or more in the tropics. If two species are caught by quite different fishing gears, e.g. herring and plaice in the North Sea, then they can be treated independently giving two independent optimum amounts of fishing and size of first capture. More often the same gear will catch several species, e.g. a North Sea trawler will catch cod, haddock and plaice. Then the mesh size in use will define the size of first capture for each species, and this with the known amount of fishing will enable the catch of each species to be calculated, and by simple addition, the total catch, in weight or value, is obtained. As before, the optimum mesh size for a given amount of fishing, or the amount of fishing giving the maximum catch with fixed mesh size, is readily determined, but these may well be different from the best, for most, if not all, species taken separately. In particular, when as in the North Sea the relatively big fish (cod and plaice) are the most important, the best mesh sizes at high rates of fishing will be so big that nearly all the small fish (e.g. whiting and sole) will get through.

The biological data needed for a conservation policy have now been outlined, though extremely sketchily; it remains to conclude by outlining even more briefly some of the objectives, methods and difficulties in practical fisheries conservation. As has been mentioned, there is no danger of any marine fish becoming extinct as a result of too much fishing; also the greatest possible catch in general would be obtained by using a very large mesh and a very great and impractical amount of fishing. It is therefore difficult to give an objective for conservation definable purely on biological grounds. Re-examination of the earlier results in economic terms enables the value of the catch to be determined, and the cost of catching it will be closely proportional to the amount of fishing, and independent of the size of first capture. Because it is independent of the cost, the size of first capture should, whatever the amount of fishing, be adjusted to give the maximum yield at that fishing rate. For a given economic situation then, the net yield of the fishery can be calculated; with increasing fishing the net yield increases from zero up to a maximum and then decreases to zero, and below at high fishing rates. This maximum does then provide a definable objective for conservation, but the position and value of the maximum will change with economic changes, or changes in the efficiency in the gear.

Many of the difficulties in applying conservation measures are the same as those causing the original state of overfishing. Stocks of marine fish belong to no one and therefore all too often no one is immediately interested in conserving them. If any one section of a fishery does apply conservation measures, e.g. one country restricts its amount of fishing, or a trawler increases its mesh size, then the fishery as a whole benefits, but those applying the measures will lose, unless they form the major part of the fishery. Therefore conservation measures have to be applied to the whole of a fishery. Its application is relatively simple when conditions throughout a fishery are relatively uniform, with say only one species of fish caught by the same gear for the same purpose; such fisheries provide several notable examples of successful conservation. In the North Sea the situation is more complex, with a wide range of fish species, gears and markets, and there are many problems to be solved, not only on the effect of conservation measures on these various fisheries, but, and more difficult, how to compensate in some form those sections that would lose during the general gain from a conservation measure. For instance in the North Sea a mesh size much greater than the present 75 mm would increase the general yield, but certain minor fisheries based mainly on small fish like sole and whiting would gain little or even lose, which has made it impossible so far to achieve an increase in mesh sizes.

Regulation of the size of meshes is not the only measure used to protect small fish; areas known to contain predominantly small fish can be closed, or the landing of fish below a certain size can be prohibited. The amount of fishing can also be controlled by a range of measures, such as catch quotas, close seasons, limitation in size or type of ship or gear, or in the number of ships engaged. Some of these measures, however, tend to reduce the efficiency of the fishery, and as much of the fruits of conservation lie not in greatly increasing the catch but in catching it at less cost, these conservation measures defeat themselves. In fact the problem of how best to benefit fully from the potential benefits of conservation, which can be easily shown to exist, has not yet been solved. The potential gains are great; in the North Sea alone the British catch of bottom-living fish is worth some £12 million a year; the cost of catching it must also be around £12 million, but under the best conservation the catch could be increased by at least 25%, to £15 million, and the cost of catching it reduced by a third, say to £8 million. The prize of £7 million each year therefore waits suitable international agreement on conservation, and it is to be hoped that it will not be too long delayed.

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